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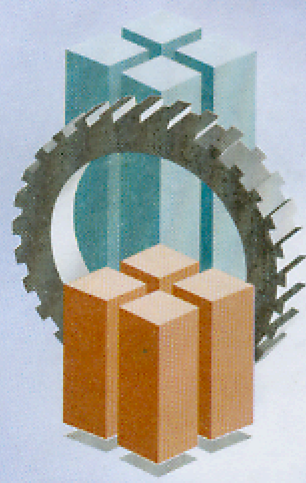

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# ADAPTIVE FUZZY FREQUENCY CONTROLLER FOR AN AGC FOR THE IMPROVEMENT OF AN ISOLATED POWER SYSTEM DYNAMICS

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**ABSTRACT**

A very important matter of discussion in power system operation is the oscillations damping problem. In this paper the authors propose a Fuzzy Frequency Controller (FFC) with Adaptive logic to improve the dynamic performance of a single-area power system. The aim of the proposed controller is to restore the frequency to its nominal value in the smallest possible time whenever there is any change in the load demand etc. Settling times & overshoots of the frequency deviation, GRC and Power Generation are compared. The controller provides a satisfactory balance between frequency overshoot and transient oscillations with zero steady-state error. All the models were simulated in Matlab 6.5-Programming environment. It is found that the proposed controller exhibits satisfactorily well dynamic performance and overcome all possible drawbacks associated with conventional PI controller.

**Key words: Adaptive Fuzzy Frequency Controller, AGC, PI Controller and Single-area power system.**

## INTRODUCTION

Load Frequency Control (LFC), or automatic generation control, is a very important issue in power system operation and control for supplying sufficient and reliable electric power. (Shayeghi, 2006). Many investigations in the area of automatic generation control (AGC) of isolated and of interconnected power systems have been reported in the past and a number of control strategies have been proposed to achieve improved performance (Karvanas, 2002). The conventional control strategy for the LFC problem is to take the integral of control error as the control signal (Ha, 2001). The proportional integral (PI) control approach is successful in achieving zero steady-state error in the frequency of the system, but it exhibits relatively poor dynamic performance as evidenced by large overshoot and transient frequency oscillations (Karvanas, 2002; Ha, 2001). Moreover, the transient settling time is relatively large. Power system parameters are a function of the operating point. Therefore, as the operating conditions change, system performance with controllers designed for a specific operating point most likely will not be satisfactory (Elgerd, 1970) . Consequently, the nonlinear nature of the load frequency control (LFC) problem makes it difficult to ensure stability for all operating points when an integral or a PI controller is used. Since the dynamics of a power system even for a reduced mathematical model is usually non-linear, time-variant and governed by strong cross-couplings of the input variables the controllers have to be designed with special care (Stefan, 2003).

Recently, fast acting artificial neural networks (ANN) have been developed. But the ANN approach has many inherent drawbacks like requiring of large historical database for proper training, network topology dependence and choice of proper response functions etc due to which exactly similar performance may not be obtained (Karvanas, 2002). More recently, in order to improve the transient response, some intelligent controllers such as FGPI, Fuzzy PI, FFC for the LFC problem is developed (Ertugrul, 2005; Hossain, 2006; Ambalal, 2005; Anower *et al.*, 2006). But a conventional Fuzzy Logic controller is used there, which has some difficulties of rules acquisition and it has some limitations also as (i) it can only deal with known nonlinearities, (ii) the controller parameters are changed in an open loop manner without feedback from the performance of the system (YI-Chiao, 1990). In addition to difficulties of rules acquisition, FLC exhibits the problem of imprecision in close-by control, which is also the weak point of human operator's control. Especially around the regions where membership

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functions assigned are not fine enough, oscillations around the set point or a certain fixed error (steady state error) may occur. This shows us the limitation of FLC and raises the need of modifying the structure of FLC to achieve satisfactory performance in both distant and close-by control.

The purpose of the dissertation research is to develop an adaptive scheme of FLC which has the rules adaptation capability to relieve the difficulty of rules acquisition and at the same time, enable the precise control of FLC. The research is focused on the representing capability of a Fuzzy model in system modeling, and the design of an Adaptive Fuzzy Frequency Controller (AFFC) to improve the transient behavior of the system. A typical single area power system is considered as a test network and simulation results are presented and discussed.

## MODEL OF AGC IN A SINGLE AREA POWER SYSTEM WITH CONTROLLER

In a single area power system, load frequency control (LFC) equipment is installed for each generator. The controllers are set for a particular operating condition and take care of small changes in load demand to maintain the frequency within the specified limit. Figure 1 shows a well known block diagram used for AGC of a typical single-area power system (Karvanas, 2002; Hadi, 2002; Elgerd, 1982) along with AFFC or conventional PI controller.

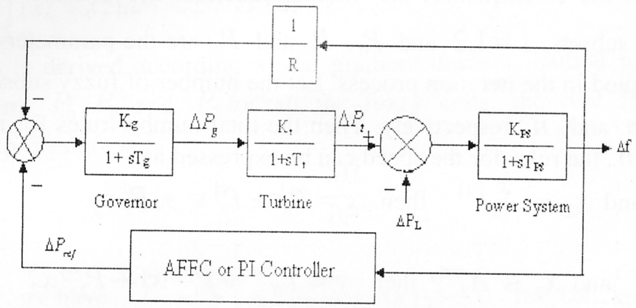



Fig. 1. Model of AGC for a typical single area power system with AFFC or PI controller.

The dynamic modeling equation in state-space variable form, obtained from the above block diagram is given as:

$$\dot{X} = AX + BU, \quad Y = CX \tag{1}$$

Where,

$$X = [\Delta f \quad \Delta P_m \quad \Delta P_V \quad \Delta P_{ref}\,]^T\,; \quad U = [\,\Delta P_L]^T$$

$$Y = [\Delta f\,]$$

are the state vector, the control vector and the output variables respectively. The values of the elements of the system matrices A, B, and C (shown in equation 2) may be computed from the nominal parameter values (Karvanas, 2002; Hadi, 2002; Elgerd, 1982).

$$A = \begin{bmatrix} -\frac{1}{T_{PS}} & \frac{K_{PS}}{T_{PS}} & 0 & 0 \\ 0 & -\frac{1}{T_t} & \frac{K_g}{T_t} & 0 \\ -\frac{K_g}{RT_g} & 0 & -\frac{1}{T_g} & -\frac{K_g}{T_g} \\ K_I & 0 & 0 & 0 \end{bmatrix}; \quad B = \begin{bmatrix} -\frac{K_{PS}}{T_{PS}} \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad and \quad C = [1 \quad 0 \quad 0 \quad 0]; \tag{2}$$

### Conventional PI control considerations

The general practice in the design of a LFC is to utilize a PI structure. A typical conventional PI control system is shown in Fig. 2.

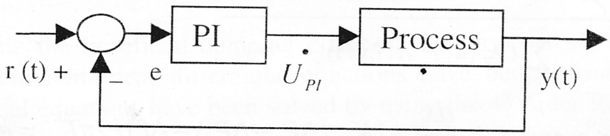



Fig. 2. A typical conventional PI controller

## DESIGN OF ADAPTIVE FUZZY FREQUENCY CONTROLLER

### Fuzzy modeling

The purpose of the fuzzy modeling is to build a fuzzy model which describes the behavior of the system by using the observed input-output data. The present modeling is based on the fuzzy modeling proposed by Sugeno (YI-Chiao, 1990; Rabbani, 1998; Sugeno, 1988) which does not require fuzzy sets defined in the output space but only in the input space. The input space is partitioned into a number of fuzzy cells by the fuzzy sets defined. A linear function of input variables is used in each fuzzy cell to describe the relation of input and output data. The final output of the fuzzy model is given by the weighted average of all local outputs. The final output will be obtained for each set of the premise variables of $\Delta\omega$ and $\Delta\dot{\omega}$. Final control for the AGC unit will be obtained after the addition of the energy feedback signal (Fig.3) (Rabbani, 1998). A general algorithm using two premise variables in each and every rule can be expressed as follows:

$$\text{if } x_1 \text{ is } A_1 \text{ and } x_2 \text{ is } A_2 \quad \text{then} \quad y = P_0 + P_1 x_1 + P_2 x_2 \tag{3}$$

where $y$ : variable of the consequence, the internal function $x_i$ : variables of the premise, $i = 1,2$

$A_i$ : reference fuzzy subsets, $i = 1,2$ and $P_0$, $P_1$ and $P_2$ are the parameters of the internal function $y$ and are to be adapted in the iteration process. Let the number of fuzzy subsets in the input spaces of $\Delta\omega$ and $\Delta\dot{\omega}$ be $m$ and $n$, respectively. Then the total number rules for the speed will be $m \times n$. Defining $mn = m \times n$, the rules for the speed can be expressed as

$$R^1 : \text{if } x_1 \text{ is } A_1^1 \text{ and } x_2 \text{ is } A_2 \quad \text{then} \quad y = P_0^1 + P_1^1 x_1 + P_2^1 x_2 \tag{4}$$

$$\vdots$$

$$R^{mn} : \text{if } x_1 \text{ is } A_1^{mn} \text{ and } x_2 \text{ is } A_2^{mn} \quad \text{then} \quad y = P_0^{mn} + P_1^{mn} x_1 + P_2^{mn} x_2 \tag{5}$$

where $x_1 = \Delta\omega$ and $x_2 = \Delta\dot{\omega}$.

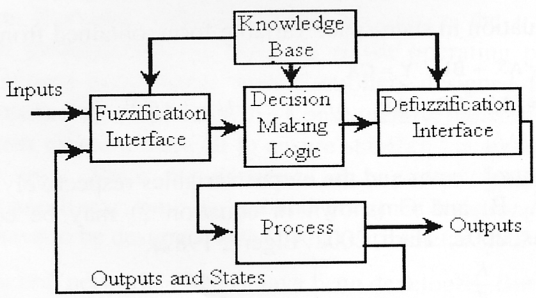



Fig. 3. Basic structure of an adaptive fuzzy controller (AFC) (YI-Chiao, 1990)

In this work, it has been selected two inputs for the FFC controller, one is the frequency deviations and another is the rate of change of the frequency deviations. The final output of the AFC, derived from the speed error and its derivative, can be evaluated by combining the local output in a weighted average manner. It can be described as:

$$P^*_{AFFC} = \frac{\sum_{i=1}^{mn} (A_1^i(x_1) \wedge A_2^i(x_2))(P_0^i + P_1^i x_1 + P_2^i x)}{\sum_{i=1}^{mn} (A_1^i(x_1) \wedge A_2^i(x_2))} \tag{6}$$

where $x_1 = \omega_{ref} - \omega = e$ and $x_2 = \dfrac{dx_1}{dt} = [K_{PS}(\Delta P_t - \Delta P_L) - \Delta f]/2\pi T_{PS} = \dot{e}$

The output of the fuzzy model is $P^{*}_{AFFC}$, the desired active power compensation from the AGC unit. Once the structure of the fuzzy model is decided, the parameters of the internal function which determine the performance of the fuzzy model need to be adapted.

**Algorithm for rule adaptation**

The output of the fuzzy model can be expressed as

$$P^{*}_{AFFC} = \sum_{i=1}^{n} B^{i}(t)(P_0^i + P_1^i x_1 + P_2^i x_2) \tag{7}$$

Where, $'i'$ is the rule number and

$$B^{i}(t) = \frac{A_1^i(x_1) \wedge A_2^i(x_2)}{\sum_{s=1}^{n} A_1^s(x_1) \wedge A_2^s(x_2)} \tag{8}$$

The value of $B^{i}(t)$ is known in the iteration process.

Let us choose a performance index

$$J = \frac{1}{2}\int_0^t (x_1^2 + x_2^2)dt \tag{9}$$

The adaptive algorithm is derived according to the gradient descent method for all parameters. To determine the parameters $P_0, P_1$ and $P_2$ for all the fuzzy cells, the cost function $J$ has to be minimized. The general procedure is

$$P^{i}_{n.new} = P^{i}_{n.old} - \alpha_n \frac{\partial J}{\partial P_n^i} \qquad n = 0,1,2 \tag{10}$$

Consider $x_1 = \Delta\omega = e$, we have $$\frac{\partial J}{\partial P_n} = \sum_{k=1}^{N}\left[ e(k)\frac{\partial e}{\partial P_n} + \dot{e}(k)\frac{\partial \dot{e}}{\partial P_n}\right] \qquad n = 0,1,2 \tag{11}$$

Where $N$ : no. of data points need to be considered in the performance index

The algorithm for the $i$ th rule becomes

$$P^{i}_{0.new} = P^{i}_{0.old} - \alpha_0 \frac{\partial J}{\partial P_0^i}; \quad P^{i}_{1.new} = P^{i}_{1.old} - \alpha_1 \frac{\partial J}{\partial P_1^i} \quad \& \quad P^{i}_{2.new} = P^{i}_{2.old} - \alpha_2 \frac{\partial J}{\partial P_2^i} \tag{12}$$

Where,

$$\frac{\partial J}{\partial P_0^i} = -\sum_{k=1}^{N}\sum_{j=1}^{k}[e(k)(k-j)b^i(j) + \dot{e}(k)b^i(j)]$$

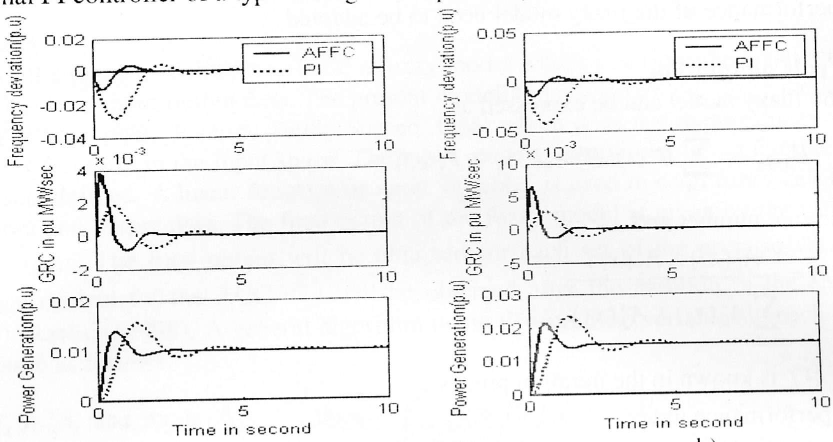
$$\frac{\partial J}{\partial P_1^i} = -\sum_{k=1}^{N}\sum_{j=1}^{k}[e(k)(k-j)b^i(j)x_1(j) + \dot{e}(k)b^i(j)x_1(j)] \tag{13}$$

$$\frac{\partial J}{\partial P_2^i} = -\sum_{k=1}^{N}\sum_{j=1}^{k}[e(k)(k-j)b^i(j)x_2(j) + \dot{e}(k)b^i(j)x_2(j)]$$

## SIMULATION RESULTS AND PERFORMANCES

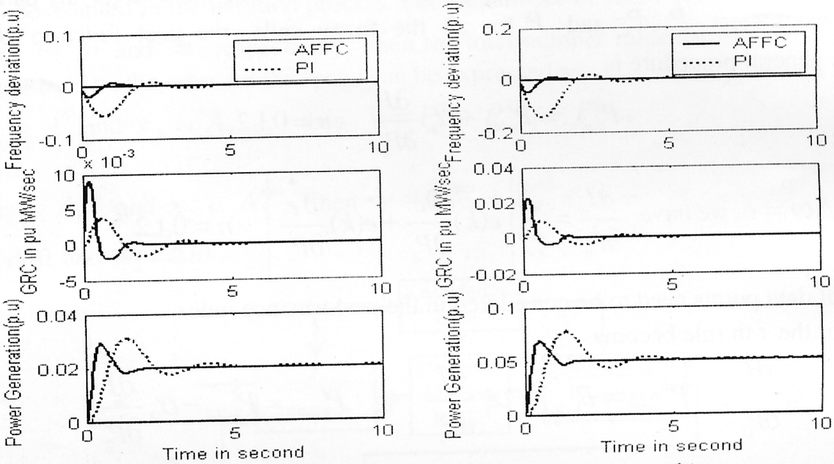
In order to demonstrate the beneficial damping effect of the proposed AFFC, computer simulation results based on system non-linear differential equations have been carried out for different load changes. The differential equations have been solved by using the 4$^{th}$ order Range-Kutta method under

MATLAB 6.5 programming environment. Fig. 4 through Fig. 6 shows the performances of the AFFC and conventional PI controller of a typical single area power system.




a) b)

Fig. 4. For step load change a) 0.01 p.u.MW and b) 0.015 p.u.MW




a) b)

Fig. 5. For step load change a) 0.02 p.u.MW and b) 0.05 p.u.MW

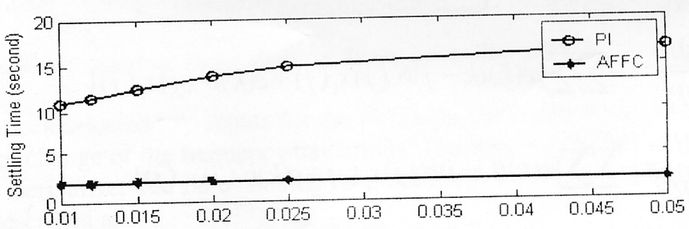



Fig. 6. A comparative settling times of AFFC and PI controller.

The step load changes $\Delta P_L$= 0.01 p.u.MW, 0.015 p.u.MW, 0.02 p.u.MW, and 0.05 p.u.MW based on total area capacity 2000MW are considered in this study. It is clearly observed from these figures that the proposed controller exhibits relatively good performances having smaller overshoot and transient frequency oscillations. The 1st peaks of the frequency deviations with AFFC are almost reduced to 75% of that the PI controller and the 2nd & 3rd peaks are almost diminished. Also the settling times with the proposed AFFC controller are greatly reduced with compare to that of the PI controller. Table 1 shows the comparative results of settling times with AFFC controller and onventional PI controller in a single-area power system.

Table 1. Settling times

| Step load change p.u. MW | Settling times | |
|---|---|---|
| | AFFC | PI |
| 0.01 | 2.00s | 7.07s |
| 0.012 | 2.05s | 7.20s |
| 0.015 | 2.10s | 7.33s |
| 0.02 | 2.30s | 7.44s |
| 0.25 | 2.31s | 7.65s |
| 0.05 | 2.32s | 7.66s |

## CONCLUSION

An intelligent load frequency controller has been developed to regulate the power output and system frequency. The proposed AFFC controller provides a satisfactory stability between frequency overshoot and transient oscillations with zero steady-state error. The various simulation results clearly indicate the superiority of the proposed LFC controller. The settling time is reduced to a great extent with the proposed mode of control. The design procedure of the AFFC controller may be applied in multi-area power systems, possibly with simpler structure and with careful examination of its potential properties.

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